SOIL POTASSIUM AS AFFECTED BY FERTILIZER TREATMENT AND CROPPING

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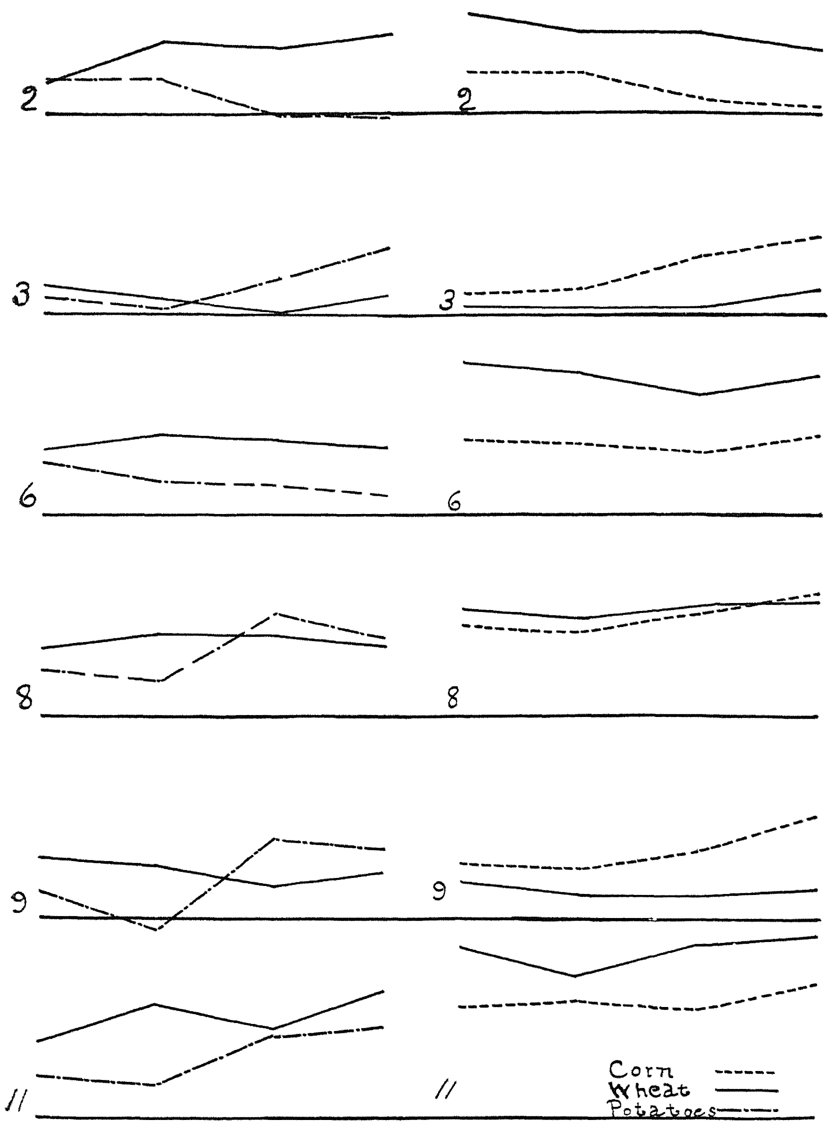

Potatoes —·-·—·- and wheat ——— in 3-year rotation with clover Four 6-year periods

Corn - - - - - and wheat ——— in 5-year rotation of corn, oats, wheat, clover, and timothy Four complete rotations

Graphs represent increases in yield over unfertilized plots. Plot 2, acid phosphate; 3, muriate of potash; 6, acid phosphate and nitrate of soda; 8, acid phosphate and muriate of potash; 9, nitrate of soda and muriate of potash; 11, nitrate of soda, acid phosphate, and muriate of potash.

Note the effect of phosphate on yields of wheat and of potash on potatoes and corn.

// BULLETIN

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SOIL POTASSIUM AS AFFECTED BY FERTILIZER TREATMENT AND CROPPING

J. W. AMES AND R. H. SIMON

The potassium content of soils of mineral origin is largely in excess of other constituents considered to be of primary importance for plant growth. An abundant amount of total potassium is not assurance, however, that an available supply will be maintained to compensate removals by increased crop yields produced by fertilizers and other additions that do not furnish potassium. Since plants differ in their requirements for and capacity to utilize potassium, the available supply in a given soil may be adequate during a longer period for some crops than for others.

Illustrations of this are furnished by the yields of potatoes and corn on certain fertility experiment plots on Wooster silt loam soil, which has a total potassium content of approximately 37,000 pounds per acre.

Potatoes, wheat, and clover have been grown in a three-year rotation for more than twenty-five years. The decreased yields of potatoes, as compared with yields of wheat and clover, on this soil where potassium was not applied, show that the quantity of potassium released from the natural supply has been inadequate for the requirements of the potato crop. There is a marked contrast in the effects of phosphorus and potassium during the first half as compared with the last half of the period thru which this rotation has continued. Phosphorus is more effective for wheat and clover, and was for potatoes also for several years after the beginning of the fertility experiments. Average yields of potatoes from several differently fertilized plots are given in Table 1.

During the greater part of the period thru which the 5-year rotation fertility experiments have been carried on, potassium has been less effective than phosphorus for all the crops grown. For the last few years, however, the corn yields on limed soil, fertilized with potassium only, have been larger than those on soil where the fertilizer treatment was acid phosphate without potassium.

TABLE 1.—EFFECT OF POTASSIUM AND OTHER FERTILIZERS ON POTATOES, IN ROTATION WITH WHEAT AND CLOVER, YIELDS PER ACRE

Plot	Fertilizer treatment, pounds per acre	25-year average 1894—1918		12-year average 1894—1905		12-year average 1906—1917	
		Yield	Increase	Yield	Increase	Yield	Increase
		Bu.	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*
1	None	137.95	....	169.03	....	110.64	....
2	Acid phosphate	145.91	7.67	190.29	18.40	107.67	−2.04
3	Muriate potash	154.45	15.91	180.78	6.01	135.25	26.45
4	None	138.83	....	177.63	....	107.87	....
5	Nitrate soda	144.97	8.43	179.57	6.55	118.17	10.61
6	Acid phosphate } Nitrate soda }	151.72	17.47	189.35	20.94	119.51	12.26
7	None	131.97	....	163.80	....	106.93	....
8	Acid phosphate } Muriate potash }	165.93	34.19	186.86	21.48	151.22	46.21
9	Muriate potash } Nitrate soda }	153.33	21.84	171.82	4.77	140.27	37.19
10	None	131.25	....	168.55	....	101.16	....

Gypsum, lime, and various fertilizer materials, including sodium nitrate, ammonium sulphate, and acid phosphate have been credited with liberating potassium, but the conclusions from various experiments conducted under dissimilar conditions with different soils do not always agree.

TABLE 2.—EFFECT OF POTASSIUM AND OTHER FERTILIZERS ON CORN GROWN EVERY SIXTH YEAR IN PLACE OF POTATOES ON POTATO-WHEAT-CLOVER PLOTS YIELDS PER ACRE

Plot	Fertilizer treatment, pounds per acre	Section C 1917		Section A 1918		Section B 1919	
		Grain	Stover	Grain	Stover	Grain	Stover
		Bu.	*Lb.*	*Bu.*	*Lb.*	*Bu.*	*Lb.*
1	None	94.86	4,220	29.71	2,000	86.29	3,200
2	Acid phosphate 160	89.14	4,180	27.71	2,140	87.43	2,960
3	Muriate potash 100	82.00	4,060	48.90	2,380	99.43	3,800
4	None	77.71	3,740	38.00	2,120	82.57	3,500
5	Nitrate soda 80	79.29	3,420	39.71	2,220	89.14	3,300
6	Acid phosphate 160 } Nitrate soda 80 }	77.43	3,340	46.29	2,340	84.86	3,440
7	None	62.29	2,820	36.57	2,080	84.57	3,160
8	Acid phosphate 160 } Muriate potash 100 }	83.43	3,940	50.57	2,680	100.86	3,700
9	Muriate potash } Nitrate soda }	75.71	3,340	40.29	2,400	97.71	3,400
10	None	69.43	3,060	24.29	1,880	79.14	3,240

The present investigation was undertaken for the purpose of ascertaining whether additions of various fertilizers have had an appreciable effect on potassium in soils that have been treated and cropped for a number of years. Solution studies of soils from fertility experiment plots were supplemented by work with mixtures of soils and fertilizer materials. Experiments with wheat plants grown in pots were also included to determine whether similar indications were furnished by the potassium assimilated by plants and the solubility of potassium in differently treated soils.

EXPERIMENTAL

Several procedures were employed for obtaining indications of the effect of various treatments on the solubility of potassium in different soils. Water extractions were made by the generally adopted method of shaking soil and water in the proportion of 1 to 5 for a definite time, and by continued percolation of water thru a column of soils. In the leaching of the soil with water three successive portions of 2000 c. c. each were passed thru the column of soil and collected separately to determine the rate at which the solubility of the potassium decreased after the first 2000 c. c. portion; subsequent additions of water passed thru the soil so slowly that about 30 days were required for the second and third leachings.

Other work in connection with the project included drying and heating of the soil previous to extraction with water and the use of centi-normal nitric acid as the solvent agency. The object of heating the soil previous to extraction was to destroy the nature of the colloidal materials that have absorption properties, in order to obtain a more complete removal of absorbed potassium. The potassium extracted from soil with water is an extremely small part of the total potassium content, and since water extractions of soils do not represent the true soil solution it is difficult to determine to what extent mineral constituents are changed to more soluble or available forms. Differentiating the actual and potential potassium supply is an especially complex proposition on account of the retentive power of the soil for this element.

WATER-SOLUBLE POTASSIUM IN FERTILIZED SOILS

The amounts of potassium in water solutions from fertility experiment plots that have been receiving various fertilizer treatments have furnished some indications of the influence of treatment and cropping on the supply. Data for water-soluble potassium have been obtained by both extraction and percolation procedures for differently treated plots on several types of soil. Considering first the 5-year rotation fertility plots on a silt loam soil, the results in Table 3 show the fluctuations occurring with the treatments.

TABLE 3.—WATER-SOLUBLE POTASSIUM FROM FERTILIZED PLOTS IN 5-YEAR ROTATION, SILT LOAM SOIL

Plot	Fertilizer treatment*	Soluble potassium		Water-soluble potassium obtained by continued extractions unlimed soil			
		Limed soil	Unlimed soil	First extract	Second extract	Third extract	Total extracted
		P. p. m.†	P. p. m.	P. p. m.	P. p. m.	P. p. m.	P. p. m.
1	None	4	10	5	5	4	14
2	Acid phosphate	6	9	8	6	4	18
3	Muriate potash	9	13	18	9	6	33
4	None	7	8	7	6	4	17
5	Nitrate soda	10	12	11	5	4	20
6	Acid phosphate, nitrate soda	9	12	11	6	4	21
7	None	9	9	7	6	4	17
8	Acid phosphate, muriate potash	8	12	13	8	5	26
9	Muriate potash, nitrate soda	10	17	15	11	7	33
10	None	10	9	6	4	3	13
11	Acid phos., muriate potash, nitrate soda	10	13	13	10	7	30
18	Manure	13	15	16	8	5	29
19	None	9	10	8	6	4	18
24	Acid phos., mur. pot., ammonium sulphate	13	14	13	8	6	27
25	None	7	10	7	6	5	18

*The fertilizer additions made during a five-year period were as follows: Acid phosphate 320 ; muriate potash, 260; and nitrate soda 440 pounds. All plots that received nitrate soda also received dried blood 50 pounds. Plot 24 received 480 pounds acid phosphate and 250 pounds ammonium sulphate.

†P. p. m., parts per million.

One-half of this section of plots has not been limed, while the other half has received additions of lime at intervals since 1901. This treatment has decidedly favored crop production, especially where fertilizers were supplied, so that the greater withdrawal from the limed soil is the explanation of the lesser amounts of water-soluble potassium extracted from the limed as compared with the unlimed soil. When potassium has been added, the water-soluble potassium extracted from both limed and unlimed soil is slightly in excess of that from unfertilized soil, but there was a somewhat larger amount from the unlimed soil.

When the soil was subjected to continuous leaching with water in percolators the potassium removed from the variously treated plots gave more marked indications of potassium residual from fertilizer additions. Diminishing amounts of potassium were contained in the successive extractions, the reduction between the first and subsequent leachings being more pronounced for soil fertilized with potassium than for unfertilized soil. Some indications of increased solubility of potassium where sodium nitrate was included in the fertilizer treatment were furnished by results obtained by both the extraction and leaching methods for water solutions of soils. The effect of sodium nitrate is more apparent in solutions from unlimed, than from the limed soil where increased yields have removed more of the active potassium. Where sodium nitrate is applied alone the amount of potassium extracted exceeds that from unfertilized soil. Altho sodium nitrate and acid phosphate used together as the fertilizer produce larger yields than either material singly, more water soluble potassium is obtained from Plot 6, receiving this treatment, than from Plot 2, treated with acid phosphate.

Water extractions of soils continuously cropped were made by the same percolation procedure employed for obtaining water extracts of the Wooster 5-year rotation series of plots. The results for this group of plots, located on soil that was originally similar to that occupied by the rotation plots, are given in Table 4.

TABLE 4.—WATER-SOLUBLE POTASSIUM FROM PLOTS ON SILT LOAM SOIL CROPPED CONTINUOUSLY WITH CORN, OATS, OR WHEAT

Crop	Plot	Fertilizer treatment pounds	Soluble potassium			
			First extract	Second extract	Third extract	Total extracted
			P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*
Corn	1	None	11	6	4	21
	2	Acid phos. 160; mur. pot. 100; sod. nit. 160	14	6	6	26
	6	Manure 5 tons	13	6	6	25
	8	Acid phos. 160; mur. pot. 100; sod. nit. 320	9	7	4	20
Oats	1	None	7	6	4	17
	2	Acid phos. 160; mur. pot. 100; sod. nit. 160	12	6	4	22
	6	Manure 5 tons	14	11	4	29
	8	Acid phos. 160; mur. pot. 100; sod. nit. 320	8	7	4	19
Wheat	1	None	10	8	7	25
	2	Acid phos. 160; mur. pot, 100; sod. nit. 120	11	8	5	24
	6	Manure 5 tons	18	10	7	35
	8	Acid phos. 160; mur. pot. 100; sod. nit. 280	11	7	5	23
		Uncultivated soil	18	5	5	28

Altho differences between the rotation and the continuously cropped soils are comparatively small, the slightly increased amount from unfertilized soil on which the same crop is grown year after year appears to agree with the smaller crop yields on these plots as compared with unfertilized plots of the rotation series. Altho the amounts of potassium added to the continuously cropped soil during a given period have been greater than the additions to the soil on which crops are grown in rotation, the water-soluble potassium extracted from the potassium treated plots gives no indication of a larger accumulation.

Water-soluble potassium was also determined in two other soils which differ from the Wooster silt loam in texture and composition. One of these soils described as a Miami clay loam has been used for fertility experiments with cereals and tobacco since 1904. The data for potassium extracted from several differently treated plots included as part of a corn-wheat-clover rotation series, and from

TABLE 5.—WATER-SOLUBLE POTASSIUM FROM CORN-WHEAT-CLOVER ROTATION FERTILITY PLOTS MIAMI CLAY LOAM SOIL

Plot	Fertilizer treatment for one rotation, pounds per acre	Soluble potassium			
		First extract	Second extract	Third extract	Total extracted
		P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*
1	None	9	2	2	13
2	Acid phosphate 240	6	3	3	12
6	Acid phosphate 240; sodium nitrate 140	8	3	2	13
9	Acid phos. 240; mur. pot. 40; sod. nitrate 300	6	3	4	13
14	Acid phos. 480; mur. pot. 80; sod. nitrate 300	7	3	5	15

plots on which tobacco is grown continuously on the Miami clay loam soil are given in Tables 5 and 6. The other soil compared with the silt loam, was a black clay. Altho this soil has a much larger total potassium content than either the silt loam or the clay loam, no more potassium was extracted from it than from the other soils

TABLE 6.—WATER-SOLUBLE POTASSIUM FROM MIAMI CLAY LOAM SOIL CONTINUOUSLY CROPPED WITH TOBACCO

Plot	Fertilizer treatment, pounds per acre	Soluble potassium			
		First extract	Second extract	Third extract	Total extract
		P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*
1	None	6	3	2	11
2	Acid phos. 160; mur. pot. 60; sod. nitrate 80	10	2	2	14
6	Acid phos. 160; mur. pot. 60; sod. nitrate 480	10	7	3	20
8	Acid phos. 320; mur. pot. 60; sod. nitrate 320	13	2	2	17
11	Manure 8 tons	13	2	2	17

containing less potassium. The results for water-soluble potassium extracted from differently treated fertility plots on the black clay soil are stated in Table 7. It will be noted that there is no increased solubility of potassium from soil of plots that have had potassium added. This is undoubtedly due to the greater fixing power of the clay soil.

EFFECT OF HEATING ON SOLUBILITY OF POTASSIUM

The fact that heating modifies the absorptive capacity of soil and causes an increased concentration of mineral constituents in solution, suggested heating soil previous to extraction with water in studying the influence of fertilizers on the soluble potassium supply. The effect of increased temperature on the solubility of mineral constituents is attributed by some investigators to changes in the nature of the colloidal material.

TABLE 7.—WATER-SOLUBLE POTASSIUM FROM SUGAR BEET-OATS-CLOVER ROTATION FERTILITY PLOTS, CLYDE CLAY SOIL

Plot	Fertilizer treatment for one rotation, pounds per acre	Water soluble potassium		
		First extract	Second extract	Total extracted
		P. p. m.	*P. p. m.*	*P. p. m.*
1	None	8	4	12
2	Acid phosphate 600	6	2	8
3	Muriate potash 200	7	3	10
4	None	7	4	11
5	Sodium nitrate 200	8	4	12
6	Acid phosphate 600; sodium nitrate 200	7	3	10
7	None	6	4	10
8	Acid phosphate 600; muriate potash 200	7	2	9
9	Muriate potash 200; sodium nitrate 200	7	4	11
10	None	6	4	10
11	Acid phos. 600; muriate potash 200; sodium nitrate 200	6	6	12
13	None	7	5	12
14	Sugar factory lime 2 tons	7	6	13
18	Manure 10 tons	7	6	13
19	None	6	5	11

Certain soils were heated in an electric muffle furnace at a temperature of 400° C. for one hour, while others were heated at 700°. Results for water-soluble potassium from some differently heated silt loam soils heated at 700° are given in Table 8.

TABLE 8.—WATER-SOLUBLE POTASSIUM EXTRACTED FROM SILT LOAM SOIL HEATED AT 700° CENTIGRADE*

Plot	Soluble potassium	
	Limed	Unlimed
	P. p. m.	*P. p. m.*
1	34	46
2	29	39
3	40	48
4	33	43
5	29	55
6	30	46
7	30	48
8	36	52
9	32	67
10	24	40
11	22	62
18	34	39
19	29	39
24	48	52

*The fertilizer treatment for these plots is stated in Table 3.

It is evident that heating has decidedly increased the water-soluble potassium. There is a consistent relation between the amounts from limed and unlimed soils and the removals of potassium by increased crop yields. Variations in the amounts of soluble potassium from individual plots also reflect the effect that certain fertilizer additions have had on the potassium content. Data for potassium in solutions from the black clay soil heated at 100, 400, and 700 degrees C. are given in Table 9. Increasing the temperature at which this soil was heated has decidedly increased the water-soluble potassium in solutions obtained by percolating water thru columns of soil. It will be noted that the potassium concentration of the first 2000 c. c. portion of leaching from soils heated at 700° was approximately twice that from the soils heated at 400°. Subsequent leachings of the soil heated at the higher temperature, however, did not contain proportionately increased amounts.

TABLE 9.—WATER-SOLUBLE POTASSIUM EXTRACTED FROM CLYDE CLAY SOIL AFTER HEATING AT TEMPERATURES OF 100°, 400°, AND 700° CENTIGRADE. SOIL SOLUTIONS OBTAINED BY PERCOLATING WATER THRU SOIL*

Plot	100°			400°			700°		
	First extract	Second extract	Third extract	First extract	Second extract	Third extract	First extract	Second extract	Third extract
	P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*
2	14	10	8	86	52	34	150	33	16
3	8	2	1	76	30	22	177	51	25
4	10	6	3	....	.....	....	205	45	20
8	12	6	3	71	42	26	160	50	35
9	8	5	2	65	25	16	135	35	25
11	10	5	2	74	26	19	173	54	29

*The fertilizer treatment for the several plots is given in Table 7.

The larger amounts of potassium released from clay soil than from silt loam by heating, indicates that the clay soil contains a considerable amount of absorbed potassium, since extraction without previous heating removed practically the same amount from both soils.

WATER SOLUTIONS BY DISPLACEMENT METHODS

This procedure for obtaining a soil extract was employed on several soils from which solutions had been obtained by the usual water-extraction method. In the experimental work with the displacement method, 1000 gm. of soil was moistened with 150 c. c. of water and placed in glass percolators. In order that water solution would be displaced from the soil in a reasonable time, it was necessary to limit the moisture content to about 15 percent, as the soil used puddled when a larger amount of water was added, and when the soil was in this condition water was displaced from the soil at such a slow rate that too much time was required. As compared with the five-to-one water extract, the concentration of potassium in the displaced solution was much greater. The displacement method was used for measuring the retention of potassium by soil and the solvent action of ammonium sulphate. These results are given in connection with other data showing effect of ammonium sulphate and other additions on the solubility of potassium. Solutions were also obtained by displacement from soils that had been variously treated. The amounts of potassium in solution thus obtained from soils that had been individually fertilized with muriate of potash, nitrate of soda, and acid phosphate were 13, 9, and 6 parts per million, respectively; and 7 parts per million from unfertilized soil. After a considerable amount of experimental work had been carried on with the displacement method, it was concluded that for obtaining indications of effects of additions on the liberation of potassium, the procedure had no special advantage over the extraction and leaching methods.

ACID-SOLUBLE POTASSIUM

Following the water extraction work with variously treated field soils, further studies of a number of these soils were made using centi-normal nitric acid as a solvent for the more active forms of potassium. Altho there is no definite assurance that dilute acid-soluble potassium is a measure of availability for plants, the information furnished may be of more significance than that from water solutions for obtaining indications of effects of treatment and cropping. There is evidence from results obtained that the greater proportion of the potassium extracted by this strength of acid is from absorbed potassium compounds resulting from decomposition of the original potassium-bearing minerals. The results for centi-normal acid-soluble potassium extracted from differently treated plots on several types of soils are stated in Tables 10 to 17, inclusive.

Considering first the acid-soluble potassium from the different soils that received no additions, other than lime on the Wooster silt loam, and lime and floats on the Strongsville clay, the results are approximately the same for one soil compared with another, excepting a decreased solubility in the case of limed as compared with unlimed silt loam, and a smaller amount from the floats-treated Strongsville clay than from the limed portion of that soil.

These variations in acid-soluble potassium from separate portions of unfertilized plots on the silt loam and clay soils also occur uniformly in the fertilized plots and are in accord with crop yields on the differently treated halves of these plots. Larger crop yields and consequently greater removal of potassium from the halves of the clay soil cross-dressed with floats and from the limed silt loam have reduced appreciably the natural supply of potassium soluble in the acid used. The potassium residual from applications of muriate

TABLE 10.—POTASSIUM EXTRACTED BY CENTI-NORMAL NITRIC ACID FROM SURFACE SOIL, 5-YEAR ROTATION CORN-OATS-WHEAT-CLOVER-TIMOTHY, WOOSTER SILT LOAM FERTILITY PLOTS

Plot	Fertilizer additions for a 5-year rotation period, pounds per acre	Potassium	
		Limed	Unlimed
		P. p. m.	*P. p. m.*
1	None	23	34
2	Acid phosphate 320	17	37
3	Muriate potash 260	36	77
4	None	23	37
5	Nitrate soda 440	23	31
6	Acid phosphate 320, nitrate soda 440	17	32
7	None	28	36
8	Acid phosphate 320, muriate 260	30	60
9	Muriate potash 260, nitrate soda 440	32	76
10	None	23	34
11	Acid phosphate 320, muriate potash 260, nitrate soda 440	31	61
18	Manure 18 tons	34	52
19	None	27	31
24	Acid phos. 480, muriate potash 260, ammonium sulphate 165	34	51
25	None	26	37

of potash is shown by the increased amounts dissolved from soils that received additions of potassium. Indications of the greater removal of both the natural supply and added potassium, by increased crops produced by certain treatments, are also furnished by the results. In the case of the Wooster silt loam the difference

TABLE 11.—POTASSIUM EXTRACTED BY CENTI-NORMAL NITRIC ACID FROM SUBSURFACE SOIL, 7 TO 15 INCHES, WOOSTER SILT LOAM FERTILITY PLOTS*

Plot	Potassium	
	Limed	Unlimed
	P. p. m.	*P. p. m.*
1	31	29
2	32	32
3	66	62
4	30	30
5	34	25
6	27	26
18	35	29
24	29	26

*The fertilizer treatment for the several plots is stated in Table 10.

in solubility of potassium from limed and unlimed portions of plots fertilized with muriate of potash shows that there has been an increased removal of added potassium from limed soil. In the case of the Strongsville clay, larger yields and consequently greater removals of potassium by crops are from floats-treated soil. Where acid phosphate has been added to limed Wooster soil, the appreciable reduction in the amounts of potassium as compared with that extracted from unfertilized soil reflects the increased removal by greater production due to fertilizing with acid phosphate.

TABLE 12.—POTASSIUM EXTRACTED BY CENTI-NORMAL NITRIC ACID FROM CONTINUOUSLY CROPPED FERTILITY PLOTS WOOSTER SILT LOAM

Plot	Fertilizer additions, pounds per acre	Potassium from corn cropped soil	Potassium from oats cropped soil
		P. p. m.	*P. p. m.*
1	None	31	37
2	Acid phosphate 160, muriate potash 100, nitrate soda 160	53	40
4	None	32	34
6	Manure 5 tons	49	47
7	None	31	34
8	Acid phosphate 160, muriate potash 100, nitrate soda 320	55	50
10	None	31	34

The centi-normal-acid-soluble potassium data for the continuously cropped soil and the potato-wheat-clover rotation plots do not give indications of effect of additions, other than potassium. Altho considerably more potassium has been applied to the continuously cropped than to the 5-year rotation fertility plots, the amount extracted does not show an increased accumulation.

TABLE 13.—POTASSIUM EXTRACTED BY CENTI-NORMAL NITRIC ACID FROM POTATO-WHEAT-CLOVER ROTATION FERTILITY PLOTS WOOSTER SILT LOAM

Plot	Fertilizer additions for a 3-year rotation period, pounds per acre	Potassium from Section A	Potassium from Section C
		P. p. m.	*P. p. m.*
1	None	25	34
2	Acid phosphate 320	25	31
3	Muriate potash 200	37	57
4	None	24	33
5	Nitrate soda 200	28	30
6	Acid phosphate 320, nitrate soda 200	22	30
7	None	27	34

That there has been an appreciable depletion of readily assimilable potassium is shown by the decrease of soluble potassium during a ten-year period. Unfertilized soil sampled from potato rotation plots in 1911 contained 54 parts per million, as compared with 25 parts extracted from soil from same plot, sampled in 1921. Samples were secured from two sections of the potato-wheat-clover rotation. Less soluble potassium was removed from Section A which has been cultivated for a much longer period than Section C. Results for the sub-surface seven to fifteen inches of silt loam from several fertilized plots, show an increased amount of soluble potassium where potassium alone was added. Potassium supplied by manure does not seem to have been carried into the sub-surface to

TABLE 14.—POTASSIUM EXTRACTED BY CENTI-NORMAL NITRIC ACID FROM FERTILITY PLOTS STRONGSVILLE CLAY SOIL

Plot	Fertilizer treatment for each 5-year rotation period, pounds per acre	Potassium from soil treated with	
		Lime*	Floats*
		P. p. m.	*P. p. m.*
1	None	42	35
2	Acid phosphate 320	53	36
3	Muriate potash 260	78	47
4	None	47	37
5	Nitrate soda 440	45	34
6	Acid phosphate 320, nitrate soda 440	40	38
7	None	45	37

*One-half of these plots cross-dressed with lime and the other half with floats.

the same extent as where muriate of potash was applied. The larger removal by crops of added potassium and the natural supply from limed than from unlimed surface soil, especially where phosphorus and nitrogen were added, had not extended to the sub-surface according to the indications furnished by the centi-normal-nitric-acid solubility data.

TABLE 15.—POTASSIUM EXTRACTED BY CENTI-NORMAL NITRIC ACID FROM TOBACCO-WHEAT-CLOVER FERTILITY PLOTS MIAMI SILT LOAM

Plot	Fertilizer treatment for each 3-year period, pounds per acre	Potassium
		P. p. m.
1	None	32
2	Acid phosphate 480	24
3	Acid phosphate 480, muriate potash 180	33
6	Acid phosphate 480, nitrate soda 240	23
8	Acid phosphate 480, muriate potash 180, nitrate soda 240	26
9	Acid phosphate 480, muriate potash 300, nitrate soda 240	30
13	Acid phosphate 720, muriate potash 180, nitrate soda 240	31
15	Acid phosphate 480, muriate potash 180, nitrate soda 360	37
16	Acid phosphate 480, muriate potash 180, ammonium sulphate 180	29
22	Acid phosphate 480, potassium nitrate 200, nitrate soda 80	32
23	Acid phosphate 480, potassium sulphate 190, nitrate soda 240	37
32	Manure, 10 tons	56
33	Manure, 20 tons	78
Unfertilized subsurface soil		45
Adjacent uncultivated surface soil		41

The acid-soluble potassium obtained from variously fertilized plots on Miami silt loam soil where tobacco is grown in rotation with wheat and clover is less than that from adjacent uncultivated soils. The results for this soil show that more of the added potassium is residual where the treatment was manure, than where potassium salts were applied. In the fertility experiments on the Miami soil, in the standard application of fertilizer in the tobacco rotation, potash was used at the rate of 90 pounds per acre, all applied to the tobacco crop in the 3-year period; while in the corn-wheat-clover rotation, 20 pounds only was added, half of this to corn and half to wheat. Altho tobacco is considered to be particularly responsive to potassium, the crop yields show that potassium has produced a larger increase of corn than of tobacco on this soil.

TABLE 16.—POTASSIUM EXTRACTED BY CENTI-NORMAL NITRIC ACID FROM CORN-WHEAT-CLOVER FERTILITY PLOTS MIAMI SILT LOAM

Plot	Fertilizer treatment for each 3-year period, pounds per acre	Potassium
		P. p. m.
	None	32
2	Acid phosphate 240	28
6	Acid phosphate 240, nitrate soda 140	28
9	Acid phosphate 240, muriate potash 40, nitrate soda 300	25
14	Acid phosphate 480, muriate potash 80, nitrate soda 300	32

One of the soils studied with regard to the effect of fertilizer treatment was a black clay, with a total potassium content of 2.34 percent, while the Wooster and Miami silt loams contain approximately 1.47, and the Strongsville soil contains 1.77 percent. Extraction with acid, however, removed no more potassium from

TABLE 17.—POTASSIUM EXTRACTED BY CENTI-NORMAL NITRIC ACID FROM FERTILITY PLOTS, CLYDE CLAY SOIL

Plot	Fertilizer treatment for each 3-year rotation, pounds per acre	Potassium
		P. p. m.
1	None	36
2	Acid phosphate 600	36
3	Muriate potash 200	52
4	None	36
5	Nitrate soda 200	42
6	Acid phosphate 600, nitrate soda 200	37
7	None	37
8	Acid phosphate 600, muriate potash 200	48
9	Muriate potash 200; nitrate soda 200	42
10	None	36
11	Acid phosphate 600, muriate potash 200, nitrate soda 200	45
13	None	37
14	Lime 2 tons	31
18	Manure 10 tons	43
19	None	35

unfertilized portions of this soil than from the other soils containing smaller amounts of total potassium. Altho there was no increase in the amount of water-soluble potassium obtained from the black clay to which potassium was added, acid extractions of this soil have removed more from potassium treated plots, indicating that some measure of absorbed potassium is furnished by extracting soil with centi-normal acid. The acid-soluble results for the silt loam soil corroborate the information furnished by corn yields obtained with certain fertilizer treatments, in showing that additions of phosphorus, nitrogen, and lime for a number of years, have gradually depleted the natural supply of assimilable potassium.

ABSORPTION OF POTASSIUM

Under this heading some results of experiments on fixation of potassium by soils previously treated are considered. Altho the primary object was to determine extractive power of centi-normal nitric acid for absorbed potassium, the results obtained show that previous liming and fertilizing with potassium have had an influence on the absorption of potassium. Wooster silt loam and Strongsville clay loam soils from limed and unlimed portions of unfertilized and potassium-treated plots were used for measuring the influence of previous treatment on absorption and for testing the effectiveness of centi-normal acid as an agency for extracting potassium considered to be in an absorbed condition.

The procedure employed was as follows: 100-gm. portions of soil were in contact with 400 c. c. of potassium-chloride solution containing .0764 gm. of potassium, for twenty-four hours. After filtering and washing free from chlorine, two extractions with centi-normal nitric acid were made. Potassium and chlorine in the filtered potassium solution exclusive of washings, after being in contact with the soil, furnished information regarding the fixation of potassium. It was found that more potassium was fixed by soil that had previously been limed, and that fertilizing with potassium decreased somewhat the amount removed from potassium-chloride solution by the soil. More pronounced indications of the influence of liming on potassium fixation are given by the Wooster silt loam than by the Strongsville clay. The Strongsville unlimed soil has received addition of rock phosphate. This treatment may have increased the supply of replaceable base in the soil. The results for absorbed potassium and solubility in centi-normal nitric acid are given in Table 18.

It will be noted that the absorption of potassium by untreated Wooster silt loam soil was 42 percent of the potassium content of the solution in contact with the soil, and 60 percent by the limed soil. Altho the fixation by soil that had addition of approximately 500 pounds of potassium during a twenty-seven year period is only slightly less than that of unfertilized soil, it indicates the presence of potassium residual from fertilizers. An estimation of the amount of potassium removed by crops from potassium treated plots during the period shows that from the unlimed soil removal of potassium has been about equal to the addition, while from the limed soil the removal has exceeded the amount applied. The natural potassium supply of the soil as well as that added has been used by crops so that undoubtedly a portion of the fertilizer potassium remains. In fact the increased amount obtained in water and acid solutions of soils that received additions of potassium is rather

TABLE 18.—SOLUBILITY OF ABSORBED POTASSIUM IN CENTI-NORMAL NITRIC ACID

Description of soil and treatment	Potassium absorbed from solution	Absorbed potassium extracted by centi-normal nitric acid		Chlorine in filtrate	Centi-normal acid neutralized by 100 gm. soil	
		First extraction	Second extraction		First extraction	Second extraction
	Percent	*Percent*	*Percent*	*Gm.*	*C. c.*	*C. c.*
Wooster silt loam: no treatment	43	48	16	.073	263	26
Wooster silt loam: lime	60	47	25	.074	370	340
Wooster silt loam: muriate potash	38	43	15	.074	279	79
Wooster silt loam: muriate potash, lime.	55	47	27	.075	488	408
Strongsville clay: no treatment	54	50	21	.073	396	201
Strongsville clay: lime	60	48	28	.074	466	365
Strongsville clay: muriate potash	50	51	20	.072	412	193
Strongsville clay: muriate potash, lime	58	51	27	.073	468	317

positive indication that such is the case. Various hypotheses have been proposed regarding the nature of the phenomena of fixation by soils. It has been attributed to both chemical and physical agencies. The fact that increasing the soils supply of easily replaceable base causes a greater fixation of potassium is regarded as strong proof that chemical interchange is an important factor involved. There was no removal of chlorine from the potassium solution by the soil, the amount in the filtrate from the soil was about the same for the several soils, .074 gm., an amount slightly in excess of .0694 gm. in the original solution in contact with the soils.

The amount of potassium extracted from the several soils by centi-normal nitric acid shows what proportion of the absorbed potassium was soluble in acid of this strength. The first treatment with acid did not indicate an increased solubility where the absorption of potassium was greater, but the second extraction recovered more from the limed soil, so that if the sum of the two extractions is taken as a measure of the potassium recovered, the amount is larger from the soil that had the greater absorption capacity. Other results from experiments with the displacement procedure for obtaining soil extract show that there was a more complete fixation from solutions of less concentration. Where potassium had been added to supply potassium at the rate of 10, 50, and 100 parts per million of soil, fixation was more than 90 percent for each of these concentrations. These amounts of potassium were supplied by solutions of potassium chloride added to soil so that the total quantity of water in contact with soil was 150 c. c. to 1,000 gm. of soil.

EFFECT OF FERTILIZER SALTS

Several procedures were employed for determining the action of salts on liberation of potassium from soil mixtures, and some of the differently treated soils that were studied with respect to solubility of potassium in water and centi-normal acid. Different amounts of salts were used, and it was found that the action of stronger concentrations of salts was more pronounced but not proportionate to increased strength of solution. Altho it is evident that weaker concentrations of salts will not furnish as decided indications as would be obtained where heavier additions were made, it was considered that the results would more accurately indicate the effect that would follow addition of fertilizer salts at the rates ordinarily applied.

The solvent action of calcium sulphate, sodium nitrate, ammonium sulphate, and mono-calcium phosphate at the rate of 5 gm. to 2,500 c. c. of water, in contact with 500 gm. of soil for twenty-four hours, was determined in unfertilized and potassium-treated soil of three types, described as Wooster silt loam, Strongsville clay, and Paulding black clay. Addition of the salts at this rate was equivalent to approximately 10,000 pounds per million of soil, which is greatly in excess of amounts that would be applied in practice. The results obtained by addition of the larger amounts of salts to unfertilized and potassium-treated silt loam, clay loam, and black clay soils are given in Table 19.

The results obtained where the heavier additions were made show that ammonium sulphate had a more pronounced effect than the other salts, and that the amounts of potassium liberated from the unfertilized portions of the three soils by ammonium sulphate are in agreement with the larger supplies of potassium in the clay and clay loam, than in the silt loam soil. Compared with the water-soluble potassium, the other salts have also increased the solubility appreciably. The increased solubility of potassium from soil treated with muriate of potash as compared with the unfertilized soil shows that the salts were effective in liberating absorbed potassium. Indications of the effect of smaller amounts of ammonium sulphate, sodium nitrate, and calcium sulphate on the liberation of potassium from differently treated soils are furnished by the data in Tables 20 and 21.

TABLE 19.—EFFECT OF SALTS ON SOLUBILITY OF POTASSIUM. UNFERTILIZED AND POTASSIUM-FERTILIZED SILT LOAM, CLAY LOAM, AND BLACK CLAY SOILS

Salt added 5 gm. to 500 gm. soil	Soluble potassium					
	Fertilizer treatment					
	None			Muriate potash		
	Silt loam	Clay loam	Black clay	Silt loam	Clay loam	Black clay
	P.p.m.	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*
Calcium sulphate	17	17	31	40	31	31
Sodium nitrate	22	37	38	48	47	47
Ammonium sulphate	41	51	90	76	72	96
Mono-calcium phosphate	20	13	....	52	29	....
Distilled water	8	7	7	17	15	6

These soils included the surface and sub-surface depths of variously treated plots on silt loam soil, as well as clay and clay loam soils on which fertility experiments are conducted. The rates at which the smaller amounts of materials were added were as follows: ammonium sulphate, 100; sodium nitrate, 200; and calcium sulphate, 400 parts per million of soil.

TABLE 20.—EFFECT OF SALTS ON SOLUBILITY OF POTASSIUM IN SURFACE AND SUBSURFACE SOIL FROM LIMED AND UNLIMED FERTILITY PLOTS, SILT LOAM SOIL

Soil treatment	Soil depth	Water soluble potassium			
		Salt added			Water only
		Calcium sulphate	Sodium nitrate	Ammonium sulphate	
		P.p.m.	*P.p.m.*	*P.p.m.*	*P.p.m.*
None	0—7 in.	9	15	13	7
	7—15 in.	9	11	12	8
Lime	0—7 in.	6	8	7	5
	7—15 in.	9	9	8	6
Acid phosphate	0—7 in.	6	7	7	5
	7—15 in.	10	10	10	6
Acid phos., lime	0—7 in.	6	7	5	4
	7—15 in.	7	8	7	6
Muriate potash	0—7 in.	17	20	22	14
	7—15 in.	14	10	16	11
Mur. potash, lime	0—7 in.	7	8	7	7
	7—15 in.	12	13	12	11
Sodium nitrate	0—7 in.	7	10	9	6
	7—15 in.	7	16	9	5
Sodium nitrate, lime	0—7 in.	7	7	7	5
	7—15 in.	8	8	8	5

The salts were added with sufficient water to satisfy the water-holding capacity, and the soil allowed to dry during a period of ten days previous to extraction with water, using five parts of water to one of soil.

Altho the amounts of water-soluble potassium extracted from soils to which smaller additions of salts were made are less than where more of the salts were added, the results for some of the soils treated give indications of increased solubility.

TABLE 21.—EFFECT OF SALTS ON SOLUBILITY OF POTASSIUM

Soil	Soluble potassium — Salt added			
	Calcium sulphate	Sodium nitrate	Ammonium sulphate	Water only
	P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*
Clyde clay, uncultivated	15	13	15	12
Clyde clay, unfertilized	12	11	15	10
Miami silt loam, uncultivated	7	8	7	7
Strongsville clay, uncultivated	15	17	21	8
Strongsville clay, unfertilized	9	15	17	8

Aside from the action of these salts in liberating potassium, the results show that there are differences in the content of more easily removable potassium, resulting from the soil treatment and cropping. In a number of instances less soluble potassium has been obtained in solutions from the limed portions of soil. Any liberating action that acid phosphate may have is generally ascribed to calcium sulphate. The results of experimental work on certain soils show that mono-calcium phosphate is about as effective as calcium sulphate. Addition of fertilizer salts in the field will no doubt have a continued action resulting in a greater solvent effect than would occur during the comparatively brief period of contact of salts with soil in the laboratory experiments.

Other results showing the effect of ammonium sulphate on solubility of potassium were obtained from solutions made by the displacement procedure. Potassium chloride in solution was added to 1,000-gm. portions of soil to supply potassium at the rate of 10, 50, and 100 parts per million of soil. After air drying, the soil was moistened with 150 c. c. of water, placed in percolators and the water displaced with alcohol. Ammonium sulphate was added to some of the portions of soil. The small additions of potassium increased slightly the concentration of the displaced solutions.

Ammonium sulphate added to the 150 c. c. of water in the proportion of 100 parts per million of soil produced a small increase of potassium in solution from the soil, and a further increase from soil to which potassium chloride had been added. The results for potassium in solutions by displacement are given in Table 22. The increased amounts of potassium carried into solution by the action of salts are comparatively small, but considering also the small quantities of salts added, the results are regarded as sufficient indication of the salts' having some effect.

TABLE 22.—POTASSIUM IN SOLUTIONS OBTAINED BY DISPLACEMENT

Additions to soil	Soluble potassium
	P. p. m.
None	9
Potassium chloride 20 p. p. m.	14
Potassium chloride 100 p. p. m.	14
Ammonium sulphate 100 p. p. m.	12
Potassium chloride 100 p. p. m. Ammonium sulphate 100 p. p. m.	21
Potassium chloride 200 p. p. m.	24
Potassium chloride 200 p. p. m. Ammonium sulphate 100 p. p. m.	28

In connection with the experimental work on addition of salts at the rate of 5 gm. to 500 gm. soil, extractions were made for the purpose of determining what effect the salts would have on potassium after a previous extraction of the soil with acid. The soil used was from a plot that had been fertilized with muriate of potash. After extraction with centi-normal nitric acid, and washing with 500 c. c. water, salts were added in solution and the extractions made in the usual manner. The results in Table 23 show that appreciable amounts were liberated by salts after 76 parts per million had been removed by previous acid extraction.

TABLE 23.—POTASSIUM REMOVED FROM SOIL BY SALTS AFTER EXTRACTION WITH CENTI-NORMAL ACID

Salt added	Soluble potassium	
	Before acid extraction	After acid extraction
	P. p. m.	*P. p. m.*
Ammonium sulphate	76	37
Sodium nitrate	48	24
Calcium sulphate	40	18

LIME AND POTASSIUM

The statement has frequently been made in the literature on soils that lime increases the availability of potassium. The results of experimental work by different investigators, however, do not generally confirm the opinion previously held regarding this effect of lime. In connection with our work on the action of various materials on potassium a test of the effect of lime was made. This experiment was carried out under somewhat different conditions with respect to contact of lime and soil, than those generally followed in other work on the subject. Soils from unfertilized and potassium-treated plots were placed in cylinders about 6 inches in diameter and 12 inches long. One portion of each soil received additions of calcium oxide at the rate of 1 gm. to 100 gms. of soil. The column of soil in each container was separated into 3-inch layers by discs of filter paper, and water was supplied thru a connecting tube at the bottom of each container, so that a capillary movement of water thru the soil was maintained. The flow of water admitted into the container was so regulated that there was no excess over that required to replace evaporation from the surface of the soil column. The object of this arrangement for capillary movement of water was to have an upward movement, and, possibly, an accumulation of soluble potassium in the surface layer of soil as water evaporated. After a period of 90 days the soil was removed and dried. Each layer of soil was extracted with decinormal nitric acid, and a water extraction made of the top layer.

TABLE 24.—LIME AND POTASSIUM SOLUBILITY

Treatment	Acid soluble potassium			
	First layer	Second layer	Third layer	Fourth layer
	P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*
Unfertilized	40	29	27	29
Unfertilized, calcium oxide addition	8	14	14	15
Muriate potash fertilizer	63	54	49	46
Muriate potash fertilizer, calcium oxide addition	59	53	48	40

No indication of lime's increasing the solubility of potassium was obtained from either the acid or water extracts of the soils treated with lime. The solubility data from the acid extractions given in Table 24 show that considerably less potassium was dissolved from the unfertilized soil with which lime was incorporated, than from soil unlimed. About the same amounts were dissolved with acid from both portions of the soil previously fertilized with muriate of potash, altho more was extracted from the bottom layer of the potassium-treated soil to which lime was added. A possible explanation of the marked difference in the soluble potassium results for the limed and unlimed portions of the unfertilized soil may be that the potassium extracted by acid from the unfertilized soil has been from the soil minerals, and since the lime added has decreased the strength of the acid, there was a smaller amount of potassium dissolved. While in the case of the soil fertilized with potassium there was no difference because the potassium was chiefly residual, in an absorbed condition. There was some upward movement and accumulation of potassium in the upper or surface layer of the unlimed portions of soil but not in the others. The water-soluble-potassium results are in Table 25.

TABLE 25.—LIME AND POTASSIUM SOLUBILITY

Treatment	Water soluble potassium
	P. p. m.
Unfertilized	6
Unfertilized, calcium oxide addition	5
Muriate potash fertilizer	9
Muriate potash fertilizer, calcium oxide addition	7

On account of the question being raised as to the part lime may have had in decreasing the solubility of potassium in one case and not in the other, determinations of the amounts of calcium soluble in centi-normal acid were made. While these figures do not have a direct bearing on the liberating action of lime on potassium, they do show that moderate applications of muriate of potash for a number of years has contributed to the depletion of the calcium supply. The average figures for soluble calcium in the four layers of soil from unfertilized and muriate-of-potash-treated plots give a difference of about 1,300 pounds of calcium, equivalent to 3,200 pounds calcium carbonate per acre. The data for acid-soluble calcium from the soils used in the lime and potassium solubility experiment are in Table 26.

TABLE 26.—CALCIUM FROM UNFERTILIZED AND MURIATE POTASH TREATED SOIL

Treatment	Acid-soluble calcium			
	First layer	Second layer	Third layer	Fourth layer
	P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*
Unfertilized	970	905	865	910
Unfertilized, calcium oxide addition	8,240	6,630	6,570	6,160
Muriate potash fertilizer	295	263	257	255
Muriate potash fertilizer, calcium oxide addition	7,150	6,930	6,695	6,320

POT EXPERIMENTS

Several series of pot experiments with young wheat plants were made for the purpose of obtaining indications from the potassium assimilated by wheat plants, regarding the effect of fertilizer salts and other additions. Some of the plants were grown in mixtures of soil with sand in order to have a more limited supply of potassium in a condition to be assimilated by plants, while others were grown in undiluted soil. The pots were kept in glass enclosures to protect the plants from dust and water. There were 10 wheat seedlings planted in each pot and grown for a period of 7 weeks. Wheat seeds were previously germinated on screens floating in pans thru which water was constantly running to remove potassium from the seeds.

POTASSIUM ASSIMILATED FROM FERTILITY PLOT SOILS

There were several lots of wheat grown in soils from limed and unlimed portions of unfertilized, acid phosphate, and muriate of potash plots. The pots contained 2,800 gm. of soil, or mixture of sand and soil, to which water was supplied by subirrigation method to maintain a moisture content of 15 percent. Some of the pots were kept in a temporary unheated glass enclosure under different conditions of temperature than prevailed in the greenhouse where other plants were grown later during the winter. Data obtained from one series of plants grown in undiluted soil from fertility plots during October and November are given in Table 27. Wheat plants

TABLE 27.—POTASSIUM REMOVAL FROM SOIL BY WHEAT GROWN OUTSIDE GREENHOUSE IN OCTOBER AND NOVEMBER

Previous additions to soil	Dry weight plants	Potassium content	Removal from soil
	Gm.	*Percent*	*P. p. m.*
None	.537	2.23	5.24
Acid phosphate	.451	2.67	4.88
Muriate potash	.455	3.39	6 23
Lime	.545	2.60	5.91
Acid phosphate; lime	.558	2.01	4.69
Muriate potash; lime	.567	2.97	7.12

grown in another series of pots outside the greenhouse in July and August, when the temperature was more favorable than for other plants grown outside, produced about the same weight of dry matter on each of the soils. The potassium content of these plants showed more marked differences than were found in plants grown under less favorable conditions. The average results for the several pots of this series given in Table 28, show that less potassium was assimilated from soil that had been receiving additions of acid phosphate than from unfertilized soil; and that the largest amount was taken up by plants grown in soil from the plot treated with muriate of potash.

TABLE 28.—POTASSIUM REMOVAL FROM DILUTED SOIL BY WHEAT GROWN OUTSIDE GREENHOUSE IN JULY AND AUGUST

Previous additions to soil	Dry weight plants	Potassium content	Removal from soil
	Gm.	*Percent*	*P. p. m.*
None	.685	3.70	18.00
Acid phosphate	.640	1.72	7.87
Muriate potash	.720	4.93	21.58

Two other series of plants were grown in mixtures of one part sand, with one part soil from limed and unlimed portions of unfertilized, acid phosphate, and potash-treated plots. The plants of one series were grown outside, and the others were grown in a greenhouse where a higher temperature prevailed. The percents of potassium in plants grown outside in sand and soil mixtures are similar to those in plants grown under the same conditions in undiluted soils; and there is also a corresponding relation between the amounts of potassium assimilated from soils of differently treated plots. With somewhat similar weights of dry matter as were produced on undiluted soil, the calculated removal from half the quantity of soil, however, is appreciably increased. The results for sand and soil mixtures just described are in Table 29. The

TABLE 29.—POTASSIUM REMOVAL FROM DILUTED SOIL BY WHEAT GROWN OUTSIDE GREENHOUSE IN OCTOBER AND NOVEMBER

Previous additions to soil	Dry weight plants	Potassium content	Removal from soil
	Gm.	*Percent*	*P. p. m.*
None	.516	2.19	9.44
Acid phosphate	.450	2.34	7 01
Muriate potash	.411	3.38	11.88
Lime	.545	2.43	9.38
Acid phosphate, lime	.458	2.01	7.76
Muriate potash, lime	.507	2.81	12.00

wheat plants grown on the same soils mixed with sand, in the greenhouse where the temperature was much higher, contained more potassium than was found in plants grown outside earlier in the season. The data furnished by this last series are given in Table 30.

A comparison of the data from these pot tests with the soluble potassium content of the fertility-plot soils shows that there is a rather consistent relation between the indications obtained for limed soil from the acid phosphate, and the muriate of potash plots. The results for the several series of pot tests show that less potassium was assimilated from the acid phosphate plot than from unfertilized soil; and an increased amount from the plot that is fertilized with potash. The smaller amount assimilated from limed than from unlimed portions of potash-treated plots also agrees with the acid-soluble potassium results for these soils.

TABLE 30.—POTASSIUM REMOVAL FROM DILUTED SOIL BY WHEAT GROWN IN GREENHOUSE

Previous additions to soil	Dry weight plants	Potassium content	Removal from soil
	Gm.	*Percent*	*P. p. m.*
None	.537	3.45	10.92
Acid phosphate	.529	3.08	9.26
Muriate of potash	.428	4.32	13.22
Lime	.444	3.72	12.91
Acid phosphate; lime	.420	3.17	11.99
Muriate potash; lime	.498	3.88	13.50

Considering the indications from analyses of soil by plants and solvents in relation to the corn yields on the limed halves of these plots during recent years, it is evident that the use of acid phosphate for an extended period has dimished the supply of available potassium.

EFFECT OF LIME ON POTASSIUM ASSIMILATED BY WHEAT PLANTS

Wheat plants were grown in separate portions of soil that were used for the experimental work with lime on potassium, in which the soil was placed in cylinders and water carried up thru the several layers of soil by capillarity. After the soils were removed from the cylinders the portions not used for solution work were dried and prepared for growing wheat seedlings. There were two portions of soil from unfertilized and two from potash-treated plots; one portion of each soil was treated with calcium oxide when placed in the cylinders. The data obtained from wheat plants grown in the four layers of soil taken from each cylinder are given in Table 31.

It will be noted that there was a decreased percentage of potassium in plants grown in soil with which lime was previously incorporated; and that plants grown in soil that had been fertilized with muriate of potash had the larger content. While the weights of plants were small, due to the conditions under which they were grown, there are variations in the dry weights obtained that are of some significance when considered in relation to their potassium content. Associated with the smaller weights of plants produced on the limed portion of the unfertilized soil, there was also a lower potassium content. In the case of the potash-treated soil that had lime added when it was placed in the cylinders, there was a larger weight of plants with a smaller percentage of potassium than was found in plants grown in soil not receiving the addition of lime.

TABLE 31.—DATA FROM WHEAT PLANTS GROWN IN SOIL USED FOR EXPERIMENTAL WORK ON EFFECT OF LIME ON POTASSIUM

Soil treatment	Soil layer	Dry weight of plants Gm.	Potassium in plants P. p. m.	Potassium removal from soil P. p. m.
Unfertilized	First	.382	2.82	22
	Second	.359	3.59	25
	Third	.394	3.25	26
	Fourth	.397	3.20	25
Average	...	.383	3.21	24
Unfertilized, lime incorporated with soil	First	.273	2.27	15
	Second	.275	2.10	12
	Third	.269	2.04	11
	Fourth	.342	1.85	13
Average	...	.290	2.06	13
Muriate of potash	First	.289	4.51	26
	Second	.269	4.13	22
	Third	.253	4.59	23
	Fourth	.279	4.09	23
Average	...	.272	4.33	23
Muriate of potash, lime incorporated with soil	First	.421	3.10	26
	Second	.279	2.91	17
	Third	.373	3.35	24
	Fourth	.409	3.72	30
Average	...	.370	3.27	24

The relations between the potassium content of plants grown on limed and unlimed portions of both soils is the same, however, in that the potassium content is lower in the soils receiving the heavy addition of lime. These results suggest that possibly calcium may have replaced potassium, inhibited assimilation, or decreased the availability. Since the acid-soluble potassium from soil and percent in plants agree, the results obtained in this particular experiment do not furnish evidence that lime increases the availability of potassium. The larger amount in plants grown on soil previously fertilized with potassium shows that where an abundant supply is furnished, plants may assimilate more than is required.

EFFECT OF ADDITIONS ON POTASSIUM ASSIMILATED BY WHEAT PLANTS

Some results pertaining to the effect of additions on liberation of potassium obtained from wheat plants grown in pot culture experiments are given in Table 32. The silt-loam soil used for this experimental work had been cultivated for a few years only, and so far as is known had not been fertilized. The amounts of materials added were not greatly in excess of the usual field applications. Sodium nitrate and potassium chloride were added in amounts equivalent to 200 pounds per acre; ammonium sulphate was added at the rate of 400 pounds; and mono-calcium phosphate supplied phosphorus equivalent to 400 pounds of 16-percent acid phosphate per acre. The other additions were calcium sulphate 800 pounds, and calcium hydroxide 4,000 pounds per acre.

TABLE 32.—POTASSIUM ASSIMILATED BY WHEAT PLANTS FROM SOILS RECEIVING ADDITIONS OF FERTILIZER SALTS

Additions	Dry weight of plants	Potassium content	Removals from soil
	Gm.	*Percent*	*P. p. m.*
None	5.25	5.50	53.50
Sodium nitrate	5.67	5.69	59.80
Ammonium sulphate	6.10	5.66	64.00
Calcium sulphate	5.70	5.78	61.00
Calcium hydroxide	5.95	5.28	58.00
Potassium chloride, calcium hydroxide	5.61	6.22	64.60
Potassium chloride	5.35	5.85	58.00
Sodium nitrate, mono-calcium phosphate	7.05	5.12	67.00
Mono-calcium phosphate	6.79	5.30	66.60
Calcium hydroxide, mono-calcium phosphate	7.23	4.45	59.60
Calcium hydroxide, sodium nitrate	5.96	5.27	58.00

The readily soluble materials were applied in sufficient water, so that the moisture content of the soil was 15 percent. Calcium sulphate and calcium hydroxide were added to dry soil previous to addition of water. All the soils were dried slowly for a period of 10 days before planting. In preparing the pots for the plants, portions of the dried soils to which additions were made were mixed with 1,800 gm. of washed sand so that each pot contained 3,600 gm. of a one to one soil and sand mixture.

There were 10 wheat seedlings transplanted in triplicate pots of each treatment and grown for a period of 6 weeks. Since there were remarkably close agreeing weights of plants and percents of potassium from pots having the same treatment, the results tabulated are dry weights of plants from 3 pots containing 5,400 gm. of soil, and the removals expressed as parts per million of soil are calculated from averaged percents of potassium in plants from 3 pots.

The weights of plants exhibit some variations that are evidently due to treatment, but there are no very marked differences in the potassium percents of the plants. There was an increased percent in plants grown in soil treated with potassium chloride and calcium hydroxide. Where slightly increased weights of plants were obtained from soils treated with sodium nitrate, ammonium sulphate, and gypsum there was no reduction in the percents of potassium, so that there was an increased removal from the soil.

The removal was largest where addition of available phosphorus and nitrogen increased the weights of plants, altho in this case the percent of potassium was decreased. Altho the additions made were small, and in contact with the soil for a rather limited period, variations in the calculated removals from the soil suggest that certain treatments may have had an influence on potassium assimilation.

SUMMARY

For the purpose of ascertaining whether additions and cropping had affected the potassium solubility, water and centi-normal acid extractions were made of soils from fertility experiment plots.

The results for potassium soluble in dilute acid show that the supply of active potassium in silt loam soil has been gradually depleted where larger yields have been produced by additions of lime and acid phosphate.

Indications of effect of sodium nitrate on soil potassium are furnished by slightly increased amounts of water soluble potassium in some soils fertilized with sodium nitrate.

Potassium residual from additions of muriate of potash and manure is shown by increased amount of soluble potassium removed from soils receiving these treatments. Soluble potassium residual from fertilizer additions is present in largest amount in unlimed soil. There was approximately the same amount dissolved from limed soil, fertilized with muriate of potash as from unfertilized and unlimed soil.

An increased amount of soluble potassium in the 7- to 15-inch sub-surface depth of soil to which muriate of potash is applied shows that an appreciable amount is carried below the cultivated depth. Potassium supplied by manure was not carried into the subsurface to the same extent as where muriate of potash was applied.

Decrease of active potassium during ten years is shown by the amounts dissolved from potato rotation plots. Unfertilized soil sampled in 1911 contained 54 parts per million, as compared with 25 parts per million ten years later.

It was found that more potassium was absorbed by limed soil that had a larger content of replaceable calcium. The absorption by limed soil was 60 percent of the potassium content of the solution in contact with the soil, and 42 percent was absorbed by unlimed soil.

Calcium sulphate, sodium nitrate, ammonium sulphate and mono-calcium phosphate at rate of 5 gm. to 2,500 c. c. of water in contact with 500 gm. soil for twenty-four hours appreciably increased solubility of potassium in unfertilized and potassium fertilized silt loam, clay loam, and clay soils. Ammonium sulphate had a more pronounced effect than the other salts added.

The effect of amounts of salts not greatly in excess of the usual fertilizer additions was determined by treating soils with ammonium sulphate at the rate of 100 parts; sodium nitrate, 200; and calcium sulphate 400 parts per million. The salts were added in sufficient water to satisfy the water holding capacity of the soils, and the soils allowed to dry for ten days previous to extraction with water. The action of these amounts of ammonium sulphate and sodium nitrate was less in the case of soils that contained smaller amounts of active potassium, according to indications furnished by acid solutions. In a number of instances ammonium sulphate and sodium nitrate dissolved more potassium from limed than from unlimed soil. Ammonium sulphate and sodium nitrate also released more potassium from unfertilized soil than from acid phosphate treated soil that had active potassium supply decreased by larger crop yields.

No evidence that lime increased solubility of potassium was furnished by results obtained from mixtures of soil and lime.